HEAT TRANSMISSION THROUGH INSULATING MATERIALS

BY

K. P. GUGIS

ARMOUR INSTITUTE OF TECHNOLOGY

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insulating materials

HEAT TRANSMISSION THROUGH INSULATING MATERIALS

A THESIS

PRESENTED BY

KASIMIR P. GUGIS

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Introduction.

The object of this thesis is to show by a series of experiments, based on heat conduction through insulating materials, how the heat transmission actually varies with the increase in the thickness of the material.

Some experiments have been carried on along this line by technical institutions and by the manufacturing associations, but results obtained were not satisfactory, therefore it has been assumed that the heat transmission varies inversely with the thickness of the material.

It is practically impossible to obtain a material which will answer for all materials and to eliminate all error.

In this case the material under test is known as a friction board, which has very small variation in thickness, is homogeneous and gives good surface contact.

As these experiments were conducted at 100° F., inlet temperature and this temperature was kept constant throughout the entire operation, it is

therefore necessary to describe the apparatus and all the arrangement in detail.

The supply water was kept in a tank 22 inches high and 15 inches inside diameter. The water was heated by means of a multiple jet burner. A small centrifugal pump, driven by an electric motor, pumped the water from the supply tank into the lower chamber of the Voorhees apparatus and then returned it to the tank with very small loss of heat.

The apparatus used in this experiment is known as the Voorhees apparatus and is shown in detail in the accompanying drawing.

It consists of two parts; the lower part, in which water circulates, and the upper part, where the ice is kept. The upper part is divided into two chambers, inner and outer. The inner chamber is 10-1/2 inches high and 7 inches in diameter. It is filled with one solid, round piece of distilled ice. The outside chamber is 15-1/2 inches high and 17 inches in diameter. It is filled with small chunks of ice surrounding the inner chamber, which is kept at a constant temperature of 32° F.

The specimen under test is placed between the upper and lower parts of the Voorhees apparatus, one side of the specimen being in contact with the upper part of the apparatus, which has a constant temperature, and the other side in contact with the lower part of the apparatus which has a temperature of 100° F., the temperature of which is also kept constant.

As will readily be seen in the drawing, the only source of heat to the inner block of ice is through the test specimen. The effective area of transmission is that directly beneath the inner vessel. Meltage from the crushed ice is discharged to waste. The meltage of the pure distilled ice is carefully weighed to one thousandth of a pound.

The heat transmission through the edges of the material do not effect the inner block of ice because the surface in contact with the inner chamber is only one-fourth that of the total area of the specimen.

In the Voorhees machine we have heat transmission purely by conduction. There are no radiation losses. Therefore we have only comparative results of the materials under test.

Details of Apparatus.

A - Distilled ice.

B - Inner chamber.

C - Crushed ice.

D - Insulation.

E - Testing specimen.

G - Copper plate.

H - Circulating water.

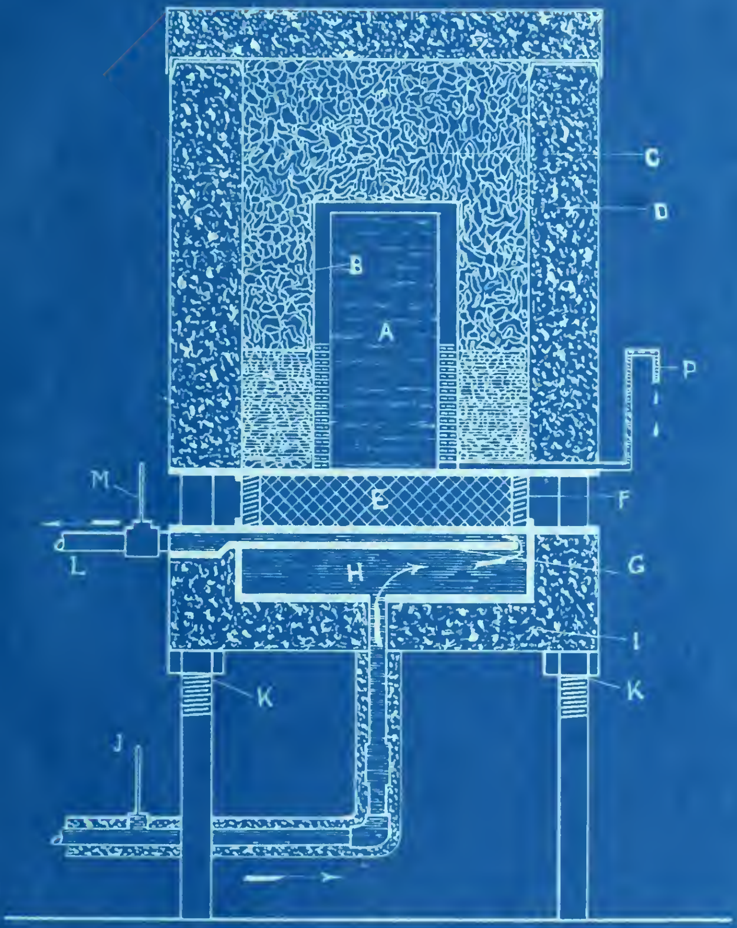
I - Insulation.

J - Thermometer for inlet water.

K - Bolts.

L - Pipe for outlet water.

M - Thermometer for outlet water.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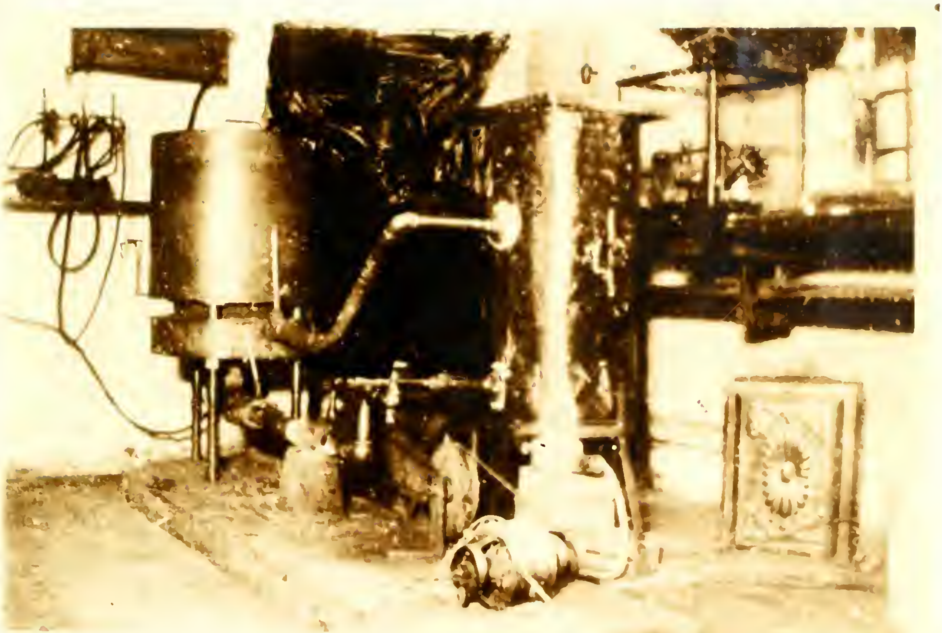


PHOTOGRAPH SHOWING FULL ARRANGEMENT OF
APPARATUS.

Weights.

The weights were compared with standard weights on a chemical balance. The errors given below show that none of the weights were in error more than 2/100 of one per cent.

The thermometers were also calibrated in an oil bath, using a standard thermometer calibrated at the United States Bureau of Standards.

50/1000 should weigh 22.680 grams
weight obtained 22.628 grams
error, .052 grams,
or 0.00011 of a pound.

#1

100/1000 should weigh 45.3600 grams
weight obtained 45.3072 grams
error, .0528 grams,
or 0.000116 of a pound.

#2.

100/1000 should weigh 45.3600 grams
weight obtained 45.3090 grams
error, .0510 grams,
or 0.000112 of a pound.

200/1000 should weigh 90.72 grams
weight obtained 90.69 grams
error, .03 gram,
or 0.00006 of a pound.

500/1000. should weigh 226.80 grams
weight obtained 226.68 grams
error, .12 gram.
or 0.00026 of a pound.

Two thermometers were used in connection with this apparatus. No. 1 for inlet water, and No. 2 for outlet water.

As compared with the standard thermometer they showed as follows:

	Degs. F.
Standard - - - - - -	100
No. 1 - - - - - - -	99
No. 2 - - - - - - -	100

So the difference between thermometer No. 1 and No. 2 is one degree.

Thickness and Density of Specimens.

Sample Number	Weight Pounds	Thickness Average Inches	Volume Cu. Inches	Density — W/V
1	1.19	0.212	32.0544	0.0371
2	1.15	0.211	31.9032	0.0361
3	1.13	0.209	31.6008	0.0358
4	1.16	0.210	31.7520	0.0365
5	1.23	0.213	32.2050	0.0382
6	1.22	0.213	32.2056	0.0380
7	1.26	0.216	32.6592	0.0386
8	1.19	0.214	32.3568	0.0368
9	1.25	0.215	32.6030	0.0384
10	1.21	0.211	31.9032	0.0339
11	1.21	0.213	32.2056	0.0370
12	1.18	0.211	31.9032	0.0370
13	1.22	0.212	32.0544	0.0371
14	1.19	0.212	32.0544	0.0371
15	1.19	0.212	32.0544	0.0371

Six runs were made and six different combinations. At each run the number of specimens was increased.

Run	Number of Specimen		Thickness
1	Nos.	1, 2	0.432
2	Nos.	1, 2, 3, 4,	0.849
3	Nos.	1, 2, 3, 4, 5, 6.	1.258
4	Nos.	1, 2, 3, 4, 5, 6. 7, 8, 9,	1.912
5	Nos.	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12,	2.548
6	Nos.	1, 2, 3. 4. 5, 6, 7. 8, 9, 10, 11, 12. 13, 14, 15,	3.184

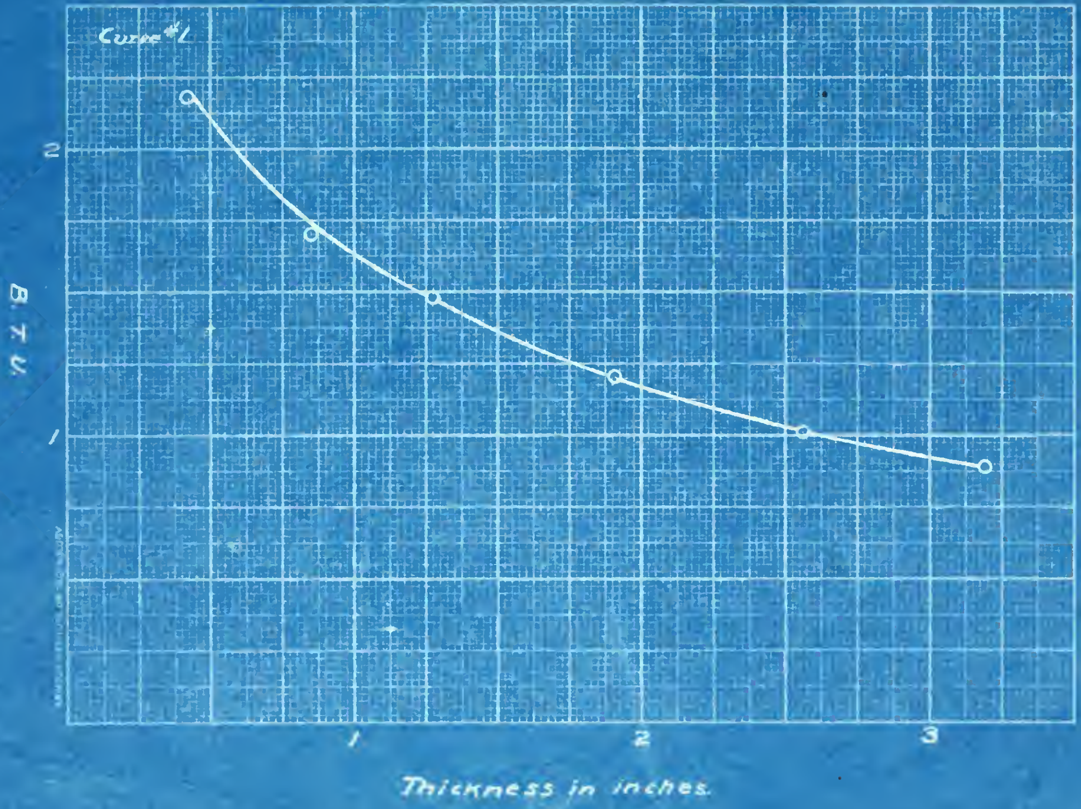
Curve No. 1 shows the heat transmission for each thickness of specimen used, ranging from about 2 B.t.u. for thickness of 0.432 inch to about 8 B.t.u. for 3.184 inch. As shown by the curve the heat dropped considerably with the first and second increase of thickness, but from there on it became less and less.

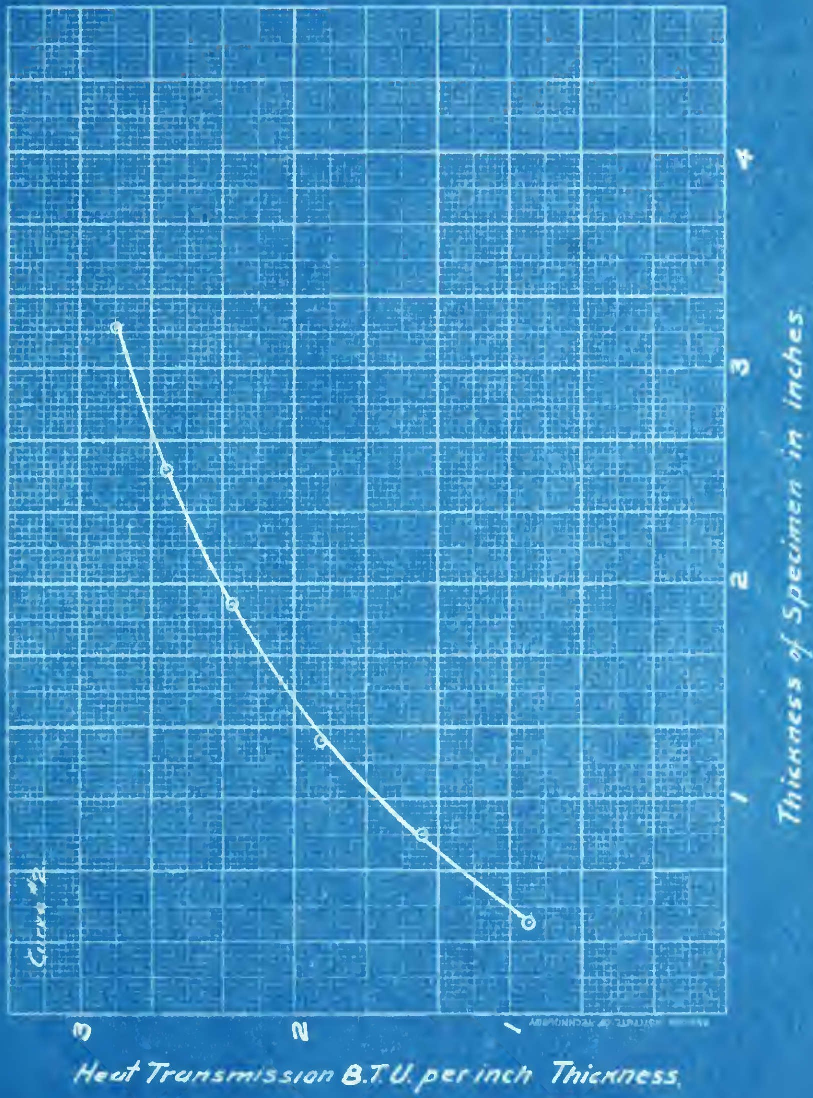
The second curve shows that as the thickness increases the B.t.u. per inch increases in the form of a curve concave upward instead of a straight line as it was thought. This disproves the old law.

This curve was obtained as follows:

Assuming that the heat transmission is inversely proportional to the thickness, the points were obtained by taking each point in the first curve and multiplying the B.t.u. by the thickness of the specimen, which gave the heat transmission in B.t.u. per inch of thickness. These points were used as ordinates and the different thicknesses as abscissas.

Thickness	B.t.u.	B,t.u. Per Inch of Thickness.
0.423	2.2	0.9306
0.842	1.71	1.43911
1.268	1.48	1.87664
1.913	1.19	2.2764
2.548	1.08	2.7518
3.184	0.885	2.8178


Curve #1
2
B. T. U.
1
1
2
3
Thickness in inches.



Curve #2
3
2
1
1
2
3
4
Thickness of Specimen in inches
Heat Transmission B.T.U. per inch Thickness.

No runs were made until all conditions were maintained constant. Pure distilled water ice was used in both the inner and the outer vessels. The temperature of the circulating water was kept just at 100° F. during the entire test.

Sample Computations of One Run.

Temperature of melting ice, 32° F.

Temperature difference between sides of specimen = Average temperature of circulating water, minus 32° F.

Latent heat of pure distilled ice is 44 B.t.u.

The area of the specimen was measured in square feet. This area was taken as the area of the inside vessel including the thickness of the copper.

$$\frac{\text{Latent heat of ice} \times \text{wt. of ice melted per hour in pounds}}{\text{Area of specimen in square feet} \times \text{temperature difference}}$$

= B.t.u. per thickness of specimen.

L O G No. 1.

DATE	TIME	Thickness of Specimen inch.	Space between Plates inch.	Temper °F Inlet	Temperat °F Outlet	Temper Differ °F	Weight in pounds Gross (Flask)	Tare (Flask and Water)	Net Water	Average (Water)	B.T.U
May 1	10:30	0.423	0.5								
May 1	2:30-3:30	0.423	0.5	99	100.5	1.5	0.119	0.389	0.270		
May 1	3:30-4:30	0.423	0.5	99	100.5	1.5	0.152	0.429	0.277		
May 1	4:30-5:30	0.423	0.5	99	100.5	1.5	0.119	0.396	0.277		
May 1	5:30-6:30	0.423	0.5	99	100.5	1.5	0.152	0.423	0.271	0.275	2.19

Remarks:

The diameter of the specimen through which the heat transmission takes place is 7 inches. The area of the same is 0.267 square feet.

$\frac{144}{0.267} = 539.25.$ This 539.25 will be constant for all calculations in these experiments.

$539.25 \times \frac{\text{Weight of ice melted per hour in pounds.}}{\text{Mean temperature minus 32}}$

$$\frac{539.25 \times 0.275}{99.75 - 32} = 2.19$$

2.19 B.t.u. X 0.423 inches = 0.926 B.t.u. for one inch thick specimen.

LOG No. 2.

DATE	TIME	Thickness of Specimen	Space between Plates	Temper °F Inlet	Temper °F Outlet	Temper °F Differ.	Weight in pounds				
							Gross (Flask)	TARE (Flask and water)	Net (water)	Averag. (water)	B.t.u.
		inch.	inch.								
May 2	9:00	0.842	0.937								
May 2	12:35-1:30	0.842	0.937	99	100.5	1.5	0.119	0.315	0.206		
May 2	1:30-2:30	0.842	0.937	99	100.5	1.5	0.152	0.367	0.215		
May 2	2:30-3:30	0.842	0.937	99	100.5	1.5	0.119	0.331	0.212		
May 2	3:30-4:30	0.842	0.937	99	100.5	1.5	0.152	0.372	0.220	0.215	1.71

Remarks:

For one inch thick specimen, 1.439 B.t.u.

L O G No. 3.

DATE	TIME	Thickness of Specimen	Space between PLATES	Temper °F Inlet	Temper °F outlet	Temperat °F Differ.	WEIGHT in pounds				B.T.U
		inch	inch				Gross (Flask)	Tare (Flask and Water)	Net Water	RIVER (water)	
May 5	8:30	1.268	1.375								
May 5	10:30-11:30	1.268	1.375	99	100.5	1.5	0.119	0.304	0.185		
May 5	11:30-12:30	1.268	1.375	99	100.5	1.5	0.152	0.340	0.188		
May 5	12:30-1:30	1.268	1.375	99	100.5	1.5	0.119	0.305	0.186		
May 5	1:30-2:30	1.268	1.375	99	100.5	1.5	0.152	0.340	0.188	0.187	1.40

Remarks:

For inch thickness of specimen, 1.376 B.t.u.

L O G No. 4.

DATE	TIME	Thickness of Specimen inch.	Space between PLATES inch	Temper °F Inlet	Temper °F Outlet	Temper Differ	WEight pounds Gross (Flask)	Tare (Flask and Water)	Nete (Water)	Averag. Water	B.t.u
May 6	9:30	1.913	2.0								
May 6	1:30-2:30	1.913	2.0	99	100.25	1.25	.152	0.302	0.150		
May 6	2:30-3:30	1.913	2.0	99	100.25	1.25	.119	0.271	0.152		
May 6	3:30-4:30	1.913	2.0	99	100.25	1.25	.152	0.301	0.149		
May 6	4:30-5:30	1.913	2.0	99	100.25	1.25	.119	0.270	0.151	0.151	1.20

Remarks:

For inch thick specimen, 2.295 B.t.u.

L O G No. 5

DATE	TIME	Thickness of Specimen inch.	Space between Plates inch	Temper oF Inlet	Temperat °F Outlet	Temper Differ.	WEIGHT in pounds				
							GROSS (Flask)	TATE (Flask and Water)	Net (Water)	Averag (Water)	B.t.u.
May 12	9:00	2.548	2.562								
May 12	2:00-3:00	2.548	2.562	99	100.25	1.25	0.152	0.280	0.130		
May 12	3:00-4:00	2.548	2.562	99	100.25	1.25	0.119	0.246	0.127		
May 12	4:00-5:00	2.548	2.562	99	100.25	1.25	0.152	0.287	0.135		
May 12	5:00-6:00	2.548	2.562	99	100.25	1.25	0.119	0.240	0.121	0.128	1.02

Remarks:

For inch thickness specimen, 2.599 B.t.u.

L O G No. 6

DATE	TIME	Thickness of Specimen inch	Space Between Plates inch	Temper °F Inlet	Temper. °F Outlet	Temper Differ.	WEIGHT in pounds Gross (Flask)	Tare (Flask and Wat)	Net (Water)	Averag (Water)	B.t.u.
May 13	9:00	3.184	3.20								
May 13	11:30-12:30	3.184	3.20	99	100.2	1.2	0.119	0.241	0.116		
May 13	12:30- 1:30	3.184	3.20	99	100.2	1.2	0.152	0.252	0.111		
May 13	1:30- 2:30	3.184	3.20	99	100.2	1.2	0.119	0.236	0.117		
May 13	2:30- 3:30	3.184	3.20	99	100.2	1.2	0.152	0.264	0.112	0.112	0.892

Remarks:

For inch thickness specimen, 2.840 B.t.u.